

Hypothesis

Yoga Therapy as a Complement to Astronaut Health and Emotional Fitness – Stress Reduction and Countermeasure Effectiveness Before, During, and in Post-Flight Rehabilitation: a Hypothesis

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ABSTRACT

Long duration spaceflight and exploration missions require increasing the effectiveness of countermeasures to the abnormal physiology that manifests itself in healthy astronauts living in space. The basic hypothesis proposed posits that yoga practices – breathing maneuvers, relaxation, meditation, and specific muscular movement – may serve this purpose by addressing as a whole, both the effects of microgravity and those of non-gravitational stressful conditions, before, during, and in post-flight rehabilitation. By providing self-directed stress relief tools the reduction in stress-related cortisol and catecholamine spikes observed throughout the space program may be expected to ameliorate microgravity-induced

changes such as immuno-deficiency and regional loss in bone architecture, as well as accelerate re-adaptation of balance and coordination, bone, muscle, and cardiovascular systems to Earth's gravity on return. Several hypotheses are presented based on the review of evidence from the scientific literature that defines physiological responses and relationships associated specifically with the practice of yoga as relevant to mission-related stress relief as well as post-flight orthostatic intolerance secondary to the central hypovolemia caused by microgravity. This hypothesis has far-reaching implications for the integration of yoga-based practices in complementing the effectiveness of current countermeasure approaches and provides direction for future research that might bridge the knowledge gap in the use of Yoga practices in the practice of space medicine.

Key words: Yoga Therapy; Stress Reduction; Countermeasure Effectiveness; Astronaut Health; Rehabilitation; Space Medicine; Emotional Fitness

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INTRODUCTION

Astronauts living in the microgravity of space experience characteristic physiological changes that become progressively more pronounced with increasing mission duration (Vernikos, 1996). This abnormal physiology that manifests itself in healthy humans during their adaptation to the microgravity of space persists despite a variety of countermeasures (CMs). Increasing the effectiveness of current CM approaches is

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therefore a matter of some importance since less than adequate practical CMs present a handicap for the emerging public space travel opportunities as well as in planning exploration missions.

Artificial gravity provided by an onboard centrifuge has been considered as a plausible option for greater CM effectiveness (Iwasa *et al.*, 2010; Young *et al.*, 2011). Limited studies using the head-down bed rest (HDBR) model to induce the effects of microgravity on the ground have supported the usefulness of centrifugation as a CM (Iwasaki *et al.*, 2001). However, serious and stable commitment is needed to support the research required to validate its use (Iwasa *et al.*, 2010; Young *et al.*, 2011). In addition to microgravity, astronauts assigned to a space mission are exposed to conditions that would be considered highly stressful, such as the undesirable pathological consequences of excessive or sustained adreno-cortical and sympatho-adrenal responses (McPhee *et al.*, 2012). In the case of cortisol (as well as other endocrine stress responding systems), excesses could exacerbate at the very least musculoskeletal, cardiovascular, gastro-intestinal, neuro-sensory, and cerebral structure and function known to be affected by microgravity. This physiological stress condition points to the importance of complementing current physical CMs (e.g., resistance exercise) to address non-gravitational aspects of spaceflight in support of overall health in space.

Stress has always been considered of primary importance in spaceflight as reflected by significant elevations in the so-called 'stress' hormones during launch and after landing (Leach-Hunton *et al.*, 1994). However, even though astronauts are selected based on their resilience and coping skills and have access to professional counseling during the flight, we propose that pre-flight training needs to include learning skills in maintaining their stress response within physiological limits.

Yoga provides a variety of common sense, practical techniques that draw on nature. Several observations have been reported in clinical literature that describes application of Yoga in the effective treatment of a range of medical disorders (Gokal *et al.*, 2007). Brownstein and Dembert (1989) described the use of yoga relaxation technique to effectively treat a USAF pilot

suffering from essential hypertension. More recently, yoga therapy in conjunction with other alternative medicine approaches has been tested in long-term lymphoma survivors (Habermann *et al.*, 2009). In addition, the first double blind NIH-funded clinical study showed Ayurvedic medicine was more effective in treating rheumatoid arthritis than methotrexate. A large-scale clinical trial is to follow (Furst *et al.*, 2011).

Our hypothesis posits that the study and practice of Yoga breathing, stretching, relaxation techniques, and meditation will provide astronauts and other space travelers with self-administered approaches for relief from physiological stress associated with the adaptation to spaceflight, as well as complement the effectiveness of physical CMs. These could be useful for:

- 1) Stress relief before and during the flight,
- 2) Post-flight support and rehabilitation, and
- 3) Counteracting in-flight symptoms.

The purpose of this paper is to present numerous hypotheses regarding the potential application(s) of Yoga during spaceflight, and a review of data from the scientific literature that defines physiological responses and relationships associated with the practice of Yoga principles. Our primary objective is to provide direction for future research that might bridge the knowledge gap(s) in the use of Yoga practices, ultimately providing a basis for assisting astronauts with stress relief before and during flight, and post-flight orthostatic intolerance secondary to the central hypervolemia caused by exposure to microgravity.

STRESS RELIEF BEFORE AND DURING FLIGHT

Astronauts face a range of stressful situations throughout a mission. These include the intense physical, mental, and emotional preparation before flight and conditions unique to spaceflight such as extravehicular activity, a heavy work schedule, and hypergravity during launch and re-entry. Important stress-related conditions during spaceflight include (but are not limited to) confinement and a change in normal living conditions such as eating, sleeping, and personal hygiene; separation from family and familiar places; human factor issues resulting from

negative social interactions with multicultural crewmates; and communication issues with ground control. Unexpected risks from equipment failure or narrow encounters with space debris are some of the more likely acute stressful issues. These general conditions may bear some similarities, but collectively differ dramatically from other modern day expeditions on Earth such as living on an Antarctic base or on a submarine.

The history of evidence of stress during space missions, from the first Mercury mission to the current International Space Station (ISS) era, has overall supported outpouring of cortisol and catecholamines that might have been expected, during and after the hypergravity of launch and re-entry, the discomfort of space sickness early in flight, and the reimposition of gravity after landing (Leach, 1992; Leach-Hunton *et al.*, 1994).

Immediately on entry into orbit, the relative absence of gravity results in unloading of the body (Convertino, 2007). As a result, inflight urinary 17-OHcorticosteroids for example, were decreased throughout Gemini VII in both astronauts (Lutwak *et al.*, 1969) and urinary cortisol was unchanged or increased in Skylab and the 2-11-day Shuttle missions, whereas plasma cortisol showed at the same time no change or a decrease, leading Gazeiko *et al.* (1990) to conclude that microgravity did not produce stress continually. The increased ratio of epinephrine (Epi) to norepinephrine (NE) might further indicate instead that the stress was emotionally triggered (Gazeiko *et al.*, 1990).

Similarly, circulating NE levels and catecholamine excretion after prolonged spaceflight were indeed reduced (Davidova *et al.*, 1989). Reductions in NE excretion in HDBR studies parallel the sustained inhibition of sympathoneuronal release, turnover and synthesis of (NE) without affecting adrenomedullary Epi secretion or renal dopamine production (Goldstein *et al.*, 1995). Direct measurement of baseline sympathetic nerve activity (MSNA) during the 16-day Neurolab Shuttle mission was only mildly elevated (Ertl *et al.*, 2002a). However, as expected, MSNA responses to the stress of lower body negative pressure (LBNP), to induce an orthostatic response in space, were increased, as was the circulating NE response (Ertl *et al.*, 2002b).

Higher levels of cortisol were also occasionally seen as missions increased beyond 30 days in both Soviet and U.S. astronauts (Macho *et al.*, 1991). Ground research studies supported Gazeiko's theory. Although plasma cortisol and excretion were consistently reported to be increased in male volunteers during horizontal (Leach *et al.*, 1973) and subsequently in HDBR (Dallman *et al.*, 1984), this was not the case when females were first similarly studied (Vernikos, *et al.*, 1993). In concurrent 7-day HDBR studies, male and female subjects differed. No increase in plasma cortisol was evident in the females, where in fact a progressive decrease in the amplitude of their cortisol daily rhythm and the mean daily circulating levels of cortisol were consistent with their observed positive attitude in the study (Vernikos *et al.*, 1993).

Anticipating that these differences were not due to gender but "emotionally triggered" as Gazeiko *et al.* had suggested (1990), all subsequent studies with male volunteers in the same facility at the Ames Research Center no longer showed increased plasma cortisol during HDBR. This stress relief was achieved by pairing a first-time volunteer with one who had experienced bed rest before (Vernikos, unpublished observations).

Stress and its endocrine response such as cortisol, preflight and during spaceflight, contribute to physiological changes such as bone and muscle loss. Stress of all types, as well as microgravity, compromise the immune system (Convertino, 2007). Microgravity affects the system at all levels from micro-organism to the whole body (Pierson *et al.*, 2007). Gravity plays a role on bacterial virulence *in vitro*, and on its resistance to antibiotics (Wilson *et al.*, 2008). Antibody production in response to immunization in space in an amphibian test system produced fewer antibodies and of poor quality (Bascove *et al.*, 2011). Lebsack and his colleagues (2010) found that spaceflight changes gene expression patterns in the thymus of mice that had spent 13 days in space. These changed genes primarily appear to affect signaling molecules involved in programmed cell death and the regulation of the stress response. Long believed that the immunosuppression in astronauts is entirely due to microgravity, this assumption was reversed when an astronaut came down with shingles the

day before he was due to launch, suggesting it was preflight stress and not space that was responsible for the viral reactivation in this case (Stowe *et al.*, 2011). Subsequent testing procedures were modified to take into account the possibility that preflight stress and certainly inflight stress underlies at least some of the immune suppression associated with spaceflight.

However, in the longer missions of up to six months on the ISS, even mild negative social stress could compromise the immune system of astronauts. A recent study (Chiang, *et al.*, 2012) showed that relatively mild, daily negative social relational interactions can affect the immune system and did so through an inflammatory mechanism. Negative social events were related to higher IL-6 and sTNF α RII (a type II soluble receptor for TNF α) and greater sensitivity to stress. Social stressors, including negative social interactions, lead to increases in cortisol (Dickerson and Kemeny, 2004; Kiecolt-Glaser *et al.*, 1997), and cortisol tends to have a suppressive effect on inflammatory processes. However, repeated exposure to negative social stress and cortisol may lead to resistance to the anti-inflammatory effects of cortisol (Miller *et al.*, 2008; Stark *et al.*, 2001). Negative social interactions also increase blood pressure and heart rate and overall sympathetic activity (Sgoifo *et al.*, 1997). Sympathetic activity has been shown to be positively related to inflammation whereas the opposite is true for parasympathetic activity (Marsland *et al.*, 2007).

Yoga practices have been found useful in reducing the immunodeficiency caused by examination stress (Gopal *et al.*, 2011) or of psychological stress in general (Kulkarni and Bera, 2009). A Scandinavian study reported that the use of yoga improved the ability to cope with stress in the workplace and improved the sense of "well-being" (Hartfiel *et al.*, 2011). People who practice Yoga regularly have lower inflammatory responses to stress with lower blood levels of interleukin-6, a component of the body's inflammatory response that contributes to heart disease, stroke, arthritis, and type-2 diabetes (Kiecolt-Glaser *et al.*, 2010). We hypothesize therefore that Yoga practice may represent an option for maintaining the immune system that astronauts may use as an adjunct to their countermeasure repertoire.

Meditation

For stress relief, meditation is a keystone of Yoga practice. Centers for Integrative Medicine that have meditation and mindfulness at their core include those led by Jeffrey Brantley, MD, at Duke University (McGonigal, 2011) and John Kabatt-Zinn, using Mindfulness-Based Stress Reduction (MBSR) at the University of Massachusetts (Fisher, 2010). To better understand how mindfulness meditation reduces stress and promotes a feeling of physical and mental well being, subjects were studied with fMRI while meditating. Midline cortical structures, including the bilateral anterior insula, left ventral anterior cingulate cortex, right prefrontal cortex, and bilateral precuneus, showed decreased signal, whereas a signal increase was noted in the right posterior cingulate cortex, supporting the theory that positive outcomes are achieved through a process of reduced sense of identity (Ives-Deliperi *et al.*, 2010). Meditation training has been gaining ground after studies evaluated its usefulness for stress reduction, anxiety, and burnout among Canadian and Spanish family physicians (Lee *et al.*, 2008; Franco, 2010). In this regard, we hypothesize that meditation may be effective as a countermeasure against emotional stress in astronauts.

Respiration Yoga Therapy Practice

In yogic terms, microgravity can be considered as a non-grounding environment, in contrast to Earth's gravitational environment, which is considered a grounding environment. A variety of Yoga body postures or poses (called āsana_s) and Yoga breathing exercises (prāṇāyāma_s) combined with finger-thumb hand gestures (mudrā_s), are claimed to provide stress-relief and many other health benefits (Sarkar and Deepak, 2009, 2011). However, there is no scientific evidence to support or dismiss the notion that Yoga postures, breathing exercises, or hand gestures would provide the same effects with the upward shift of abdominal organs and blood volume induced by the microgravity environment of space, or that the reduced stress response associated with Yoga might provide protection against some of the deleterious physiological adaptations induced by living in the microgravity environment.

POST-FLIGHT SUPPORT AND REHABILITATION

On return from spaceflight, the body of an astronaut changes in an attempt to adapt to living without the load, downward pull, and directional information that gravity on Earth normally provides. During spaceflight, the demand on the body is not only to re-adapt to living in Earth's 1g, but first, to withstand the stress of increased gravity or hypergravity during the re-entry. The immediate post-flight response is characterized by orthostatic hypotension (OH), the tendency to faint on standing up, muscle weakness with balance and coordination problems, all of which hamper mobility, especially critical in an emergency situation. It is followed by a long recovery process to restore muscle and bone strength and mass, balance and coordination, and a variety of metabolic changes to their Earth-adjusted norm. The duration of the process of recovery depends on the length of the flight as well as the efficiency and effectiveness of the rehabilitation measures, and compliance on the part of the astronauts. We hypothesize that Yoga breathing practices as well as yoga muscle and joint exercises performed by astronauts in space represent one approach that may prove effective in the restoration of normal function sooner during recovery on Earth without the risk of injury imposed by regular structured exercise.

Accelerating Constructive Rehabilitation, Balance, and Coordination

We further hypothesize that small isometric and resistive Yoga activities complementary to traditional exercise may be of particular benefit, specifically in accelerating rehabilitation post-flight when proper bone architecture recovery is so crucial (Vernikos and Schneider, 2010). In addition, Yoga practice during rehabilitation might also be of value in accelerating the restoration of balance and coordination, as has been demonstrated in stroke victims (Schmid *et al.*, 2011). Balance and coordination are severely compromised by adaptation to microgravity. While in space, the balance system loses the up and down cues that gravity on Earth provides. It adapts by making the best use of the other senses (Young *et al.*, 1984). On return to Earth, the reintroduction of gravity into the equation takes

re-adaptation over a period of time. On landing, an astronaut may lose their sense of falling when tilted forward with their eyes closed, until using gravity as the prime reference for the vertical is re-established. After returning from space, astronauts find that even small head movements, such as inclining the head even slightly, may give an exaggerated sensation of tumbling forward. Leaning the head sideways feels like a significant lean (Clement *et al.*, 2003). The link between Yoga practices that enhance the relationship of gravity, balance, and coordination on Earth may be expected to enhance rehabilitation following spaceflight.

Post-flight Orthostatic Hypotension (OH)

Orthostatic intolerance (OI) is characterized by low blood pressure and the inability to continue standing without feeling faint. OI is experienced by about half the male and most female astronauts on return to Earth from flights of any duration (Waters *et al.*, 2002). Considerable research has demonstrated that the standard approach of salt solution drink before re-entry has been less than effective in ameliorating post-spaceflight OI (Vernikos and Convertino, 1994). It had been observed (Rickards *et al.*, 2007a) that OI symptoms experienced in individuals during standing, e.g., light-headedness or dizziness, were associated with reduced cerebral blood flow. A more recent investigation that was conducted on 27 astronauts following their Space Shuttle missions lasting from 8 to 16 days (Blaber *et al.*, 2011) revealed that OH and intolerance to standing after flight were also associated with reduced cerebral blood flow. On the other hand, a higher cerebral blood flow was characteristic of those astronauts who completed 10 minutes of standing without difficulty. It follows that the use of maneuvers that can increase cerebral blood flow might reduce the incidence of OI after return to Earth.

One of the maneuvers used by those practicing Yoga is slow, deep breathing. Deep inspirations lower the pressure (i.e., create a vacuum) inside the thorax (Moreno *et al.*, 1967). The resulting negative intrathoracic pressure is transferred to the brain and the resulting elevation in pressure difference between the arterial circulation and the brain results in increased cerebral blood flow. This effect has been

eloquently demonstrated through experiments in both animals and humans in which the intrathoracic and intracranial pressures can be dramatically reduced by the application of resistance during inspiration (Convertino *et al.*, 2011), resulting in significantly higher cerebral function (Rickards *et al.*, 2007b). More importantly, the interaction between lower intrathoracic pressure and increased cerebral blood flow induced by slower and deeper breaths with the use of resistance inspiration has been shown to improve tolerance to standing and other conditions that can result in fainting (Convertino *et al.*, 2011).

The benefit of slower and deeper breaths on cerebral blood flow and OI is clearly evident by the data presented in Figure 1 collected from the same individual under two conditions that produced different breathing patterns. In these experiments, the subject underwent exposure to lower body negative pressure (LBNP), a technique that has been used for decades in the space program to cause shifting of blood from the upper body to the lower extremities similar to that experienced when we stand.

The two panels in Figure 1A represent the breathing and cerebral blood flow responses to a central hypovolemia induced by LBNP. This level of LBNP caused this person to become presyncopal while breathing at 0.28 Hz without resistance during inspiration (16.5 breaths per minute; lower left panel), but was feeling fine at the same level of LBNP when breathing slower and deeper at 0.20 Hz through greater reduction in intrathoracic pressure caused by resistance inspiration (~11 breaths per minute; lower right panel). When the person was breathing slower at 0.20 Hz: 1) mean blood flow (velocity) in the middle cerebral artery (Mean MCAv) was greater (upper panels); 2) the magnitude of Mean MCAv oscillations was greater (upper panels) and associated with greater cerebral perfusion and no symptoms (Rickards *et al.*, 2007b); and 3) respiratory rate (measured in the lower panel by end-tidal CO₂) is very regular (i.e., controlled) at 0.20 Hz, but irregular at 0.28 Hz. Although these responses are presented in a single individual for demonstration purposes, they reflect those of the general population (Rickards *et al.*, 2007b).

Figure 1B shows a frequency analysis plot of the same data as in Figure 1A. If the breathing is

controlled, the frequency of breathing is represented by a single “spike” as compared to multiple “spikes” if the breathing is not controlled. It is clear from these data that regular controlled slow deep breathing is associated with greater cerebral perfusion (greater magnitude and oscillations of blood flow), less hypotension, virtually no symptoms, and greater orthostatic tolerance. We hypothesize, therefore, that the results of these experiments support the notion that the practice of Yoga could also be effective in preventing post-flight OI.

Specifically, the Yogic respiration exercises as described in Sarkar and Deepak (2011) – Bellows, Victorious, Straw-like rolled tongue, and other Yoga Breathing exercises with inspiration resistance – all involve active inhalation that would decrease intra-thoracic pressure. The best-known of these is Resistive Breathing, called Ujjayi-Prāṇāyāma (U-P), or Victorious Breathing Exercise (VBE; the name “ujjayī” literally means victorious). U-P or VBE is performed by slowly breathing through a constricted larynx, as if breathing through a straw within the throat. Since resistive inspiration increases cerebral blood flow and improves OI, we hypothesize that U-P or VBE could similarly be effective in preventing post-spaceflight orthostatic hypotension in astronauts.

COUNTERACTING INFLIGHT SYMPTOMS

Deconditioning during spaceflight affects every organ and system in the body, evident initially with space sickness followed by metabolic and cardiovascular changes in organ mass and function (Vernikos, 1996). Current CM precautions include an array of traditional exercises and some nutritional approaches. The extent of inflight physiological changes progress in the presence of these CMs at a considerable rate. Any non-invasive intervention, such as those found in yogic practice, may complement and enhance the effectiveness of CMs currently prescribed.

Space Sickness in Flight

Space sickness that occurs in a large proportion of space travelers during the first two to four days of flight (and sometimes on return to Earth) has evaded reliable preventive treatment.

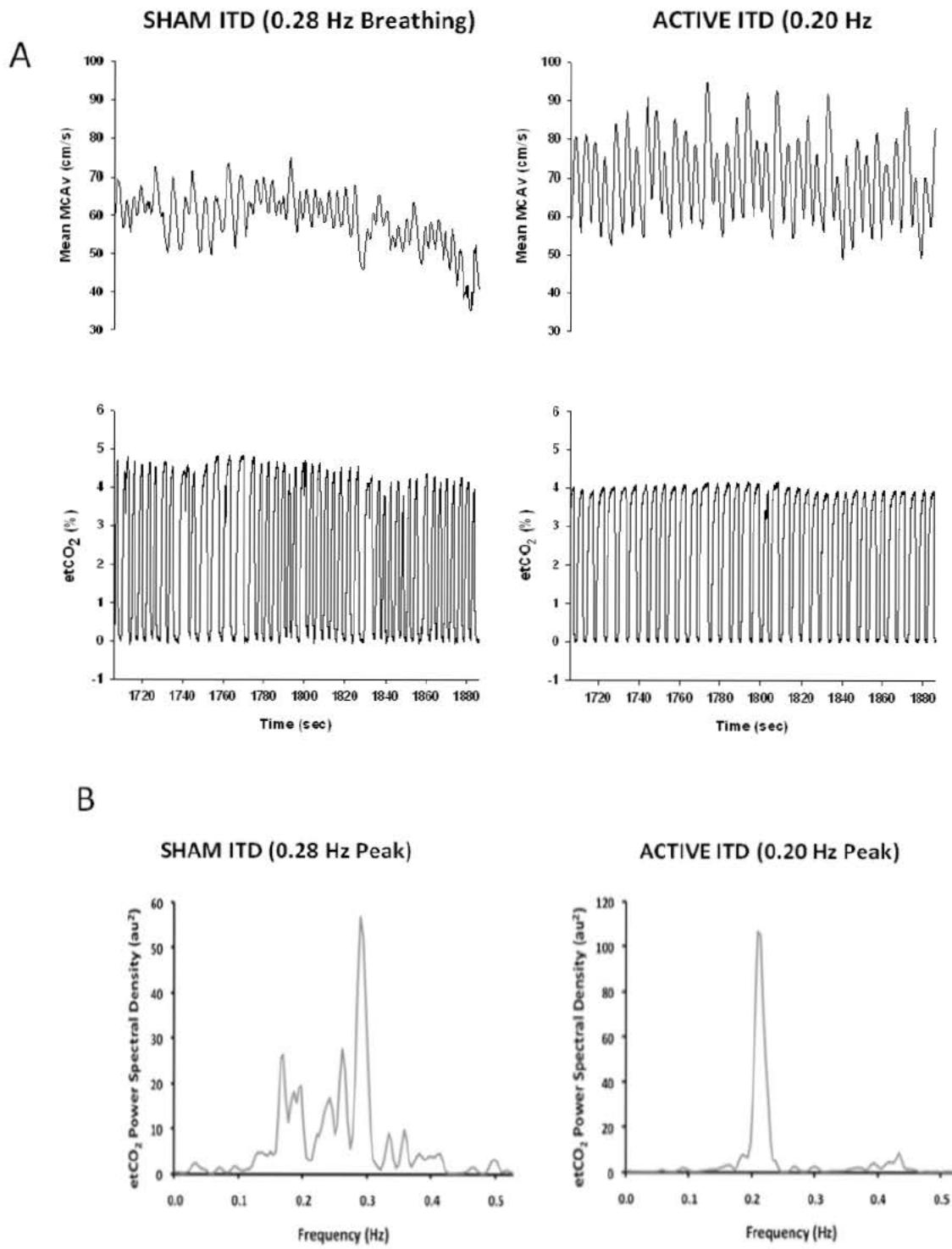


Figure 1. The two panels in Figure 1A represent the breathing and cerebral blood flow responses to a central hypovolemia induced by LBNP. Figure 1B shows a frequency analysis plot of the same data as in Figure 1A. If the breathing is controlled, the frequency of breathing is represented by a single “spike” as compared to multiple “spikes” if the breathing is not controlled. Figures 1A and 1B are adapted from Rickards *et al.*, 2007b.

As with OI, nausea and motion sickness are also associated with a decrease in cerebral blood flow (Serrador *et al.*, 2005). Since controlled breathing with slower and deeper inspiration is associated with increased cerebral blood flow, we hypothesize the possibility that Yoga may provide relief from the nausea associated with early exposure to microgravity, which would be particularly relevant to the commercial space travelers of tomorrow whose early missions would only last for a few hours or days, when space sickness could ruin the pleasurable experience of a lifetime.

We hypothesize that breathing designed to decrease intra-thoracic and intra-cranial pressure and thereby increase cerebral blood flow, provided by slow, deep inspirations, particularly with resistance inspiration, should adequately assist space travelers from fainting in response to standing on return from flight as well as from space sickness during the early portions of flight.

In-flight Musculoskeletal Loss and Post-flight Rehabilitation

More sophisticated techniques and longer duration exposures to space as on the ISS have drawn attention to the seriousness of the continuing rate of loss in bone and muscle in the microgravity of space despite rigorous countermeasures (Vernikos and Schneider, 2010). These have mainly focused on providing aerobic and resistive physical exercise according to regimes practiced on Earth's gravity (1g) such as a single bout of intense exercise once a day. Extending the duration and intensity of the exercise has helped marginally.

Spaceflight differs from Earth in that the reduced loading on muscles and bones during physical exercise makes the CM less effective. Unlike Earth, where non-exercise activities continue in 1g when exercise stops, the astronaut returns to a relative unloading of microgravity in space. To bridge this gap in non-exercise activity, we hypothesize that Yoga practice that requires no setting up of complicated equipment could be useful in providing forces on the musculoskeletal system by stretching and flexing movements throughout the non-exercise day, and reaching muscles such as those that support the spine that evade traditional exercise.

Finally, we hypothesize that yogic activities involving frequent and repetitive ankle, toe, or other flexion may well contribute to increased blood flow to muscle and bone regions, as well as tendon and ligament stimulation, and muscle contractions in a way that could encourage healthy bone architecture, as has been suggested by Rittweger and Felsenberg (2009).

CONCLUSIONS

Thus, based on data from the scientific literature that links various postures, muscular movement, and breathing maneuvers used during performance of yogic activities, we hypothesize that the wealth of approaches in Yoga practice may provide options that can be added to an astronaut's personal health kit. Breathing and mental practices may in themselves be used as powerful stress management and non-medicinal CM tools. Others may need validation in an actual or simulated spaceflight environment.

The benefits of regular Yoga practice continue to be documented. These activities will not cause pain or injury as long as they are learned and practiced under the charge of a medically trained Yoga Therapy practitioner. Learning, practice, and education are crucial to the effective and safe use of Yoga exercises, and should be started early in the pre-flight training period so that they become a habitual practice. Our hypothesis acknowledges that stress and the microgravity of space disturb the balance of the adrenocortical, autonomic, and immune systems resulting in a generalized inflammatory response. Our hypotheses also reflect the need for more evidence that yoga practices can be used to restore balance and thereby complement the effectiveness of current CMs used during spaceflight. In this we are in strong agreement with Streeter *et al.* (2012) whose recent hypothesis proposes parallel application of Yoga practices for the treatment of medical conditions exacerbated by stress. Regardless of the physiological benefits that such complementary Yoga approaches provide, the significance of further investigation into the potential psychosomatic benefits of the sense of controllability by the astronaut should not be undervalued.

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